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Initial Review of the Treatment Operations at the Installation Logistics Center Fort Lewis, Washington

K. J. Cantrell
T. L. Liikala
T. J. Gilmore
G. V. Last

July 1998

Prepared for the U.S. Army Forces Command
Through a Related Services Agreement
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under Contract DE-AC06-76RLO 1830

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Richland, Washington 99352

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Summary

An initial review was conducted of the current treatment operations for remediation of groundwater contaminated with trichloroethene (TCE) at the Fort Lewis Logistics Center. Results from this review indicate the two pump-and-treat systems are effectively containing the TCE plume within the upper unconfined aquifer (Vashon Drift). However, mass balance calculations show the existing treatment systems alone will not accomplish the remedial action objective of cleaning up the aquifer to drinking water standards within 30 years as specified in the Record of Decision (ROD). This conclusion is based on the estimated mass of TCE at the source term (51,000 kg), the calculated mass of TCE in the aquifer (4900 kg), and the removal rate of the pump-and-treat systems that currently ranges from 324 to 667 kg of TCE per year. Assuming this removal rate remains constant and volatilization is insignificant, it would require between 76 and 160 years to clean up the aquifer. In practice, however, the extraction efficiency of the pump-and-treat systems will decrease continuously through time, greatly increasing the actual cleanup time. Contamination within the lower confined aquifer (Salmon Springs Drift) is not addressed in this review.

Four areas within the TCE plume have been identified where enhancements could be made to the existing treatment operations. These are, Area 1 – the vadose zone source, Area 2 – the saturated zone source, Area 3 – a containment area downgradient of Areas 1 and 2, and Area 4 – the remainder of the plume. This report lists several remedial technologies including new and innovative (nonstandard) technologies for these four areas that may help clean up the site to regulatory acceptable levels, shorten the timeframe for cleanup, or significantly reduce currently estimated Installation Restoration Program (IRP) life-cycle costs. Based upon the estimated large quantity of TCE associated with the source term, it is clear the greatest reduction in time for remediation would be obtained by elimination or isolation of the vadose and saturated zone source terms. Planned characterization activities will likely preclude any further work in these areas at this time.

Acronyms and Abbreviations

DCE	dichloroethylene
DNAPL	dense nonaqueous phase liquid
DoD	Department of Defense
DRMO	Defense Reutilization and Marketing Office
Ecology	Washington State Department of Ecology
EGDY	East Gate Disposal Yard
EPA	Environmental Protection Agency
FFA	Federal Facilities Agreement
FORSCOM	(U.S. Army) Forces Command
gm/cm^3	grams per cubic centimeter
IGRS	In Situ Gaseous Reduction System
IRP	Installation Restoration Program
kg	kilogram
L/kg	Liters per kilogram
LNAPL	light nonaqueous phase liquid
µg/L	micrograms per Liter
mg/L	milligrams per Liter
MSL	mean sea level
NAPL	nonaqueous phase liquid
PNNL	Pacific Northwest National Laboratory
POL	petroleum, oil, and lubricants
ROD	Record of Decision
SPSH	Six-Phase Soil Heating
SVE	soil vapor extraction
TCA	trichloroethane
TCE	trichloroethene
USACE	U.S. Army Corps of Engineers
VC	vinyl chloride
VOC	volatile organic compounds

Acknowledgments

The authors wish to acknowledge the helpful technical reviews of C. R. Cole, J. W. Lindberg, J. S. Fruchter, and K. B. Olsen. We also thank M. D. Sweeney and P. D. Thorne for their assistance in the construction of Figure 1.1 and N. D. Foote for her editorial assistance.

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1.0 Introduction

The Defense Environmental Restoration Program is continually faced with the problem of allocating limited Congressionally authorized funds to achieve environmental restoration objectives. The quantity of work identified by individual Department of Defense (DoD) installations greatly exceeds the level of funding allocated in a single year. Therefore, DoD must efficiently and effectively assess, prioritize, and remediate their hazardous waste sites to protect human health and the environment.

Fort Lewis is a U.S. Army Forces Command (FORSCOM) installation located in western Washington, approximately 10 miles south of Tacoma. The installation Logistics Center was placed on the National Priorities List in December 1989, as a result of TCE contamination in groundwater beneath the site (Figure 1.1). A Federal Facilities Agreement (FFA) between the Environmental Protection Agency (EPA), the Washington State Department of Ecology (Ecology), and the Army was formalized in January 1990. This FFA established a procedural framework and schedule for developing, implementing, and monitoring appropriate response actions at the Logistics Center. A Record of Decision (ROD) was signed by EPA, Ecology, and the Army in September 1990. The selected remedial action consists of two pump-and-treat systems to treat groundwater in the upper unconfined aquifer, and further investigation of the lower aquifer and remaining potential sources of soil contamination. The first system was designed for plume containment and consists of a series of extraction wells, a treatment facility, and recharge galleries near the northwestern edge of the site. A second system was designed to contain and remediate the source area (East Gate Disposal Yard [EGDY]), and facilitate the flushing of secondary groundwater sources within the high concentration zones beneath the EGDY.

Fort Lewis requested Pacific Northwest National Laboratory (PNNL) visit the installation and perform an initial review the treatment operations at the Logistics Center. From this visit and a review of supporting documentation provided by Fort Lewis, PNNL has identified enhancement opportunities with respect to the current treatment operations. Potential enhancement opportunities include identifying changes to accelerate cleanup/treatment through implementation of enhanced or innovative (nonstandard) technologies and significantly reducing currently identified site Installation Restoration Program (IRP) life-cycle costs.

PNNL approached this work in four steps:

1. An initial data review was performed, including the IRP Action Plan and supporting documentation.

2. A site visit was conducted to review the treatment operations and assess site-specific conditions. Additional documents, identified in the initial review, were collected.

3. At the conclusion of the initial information review and site visit, discussions were held with Fort Lewis on enhancement opportunities for accelerated cleanup and reduced costs through the use of innovative technologies. The outcome of this discussion was to reach consensus on the general content and format of this report, with the focus on the upper unconfined aquifer.

4. This report was prepared to document the results of the evaluation of current treatment operations and subsequent enhancement opportunities.

This report is organized as follows. Background information on disposal practices at the Logistics Center is given in Section 2.0. Section 3.0 describes the hydrogeologic framework beneath the site. Section 4.0 contains a source term evaluation. An evaluation of the existing pump-and-treat systems and areas for enhancing those systems are presented in Sections 5.0 and 6.0, respectively. Innovative technology options are given in Section 7.0. Conclusions are provided in Section 8.0. References cited in the text are listed in Section 9.0.

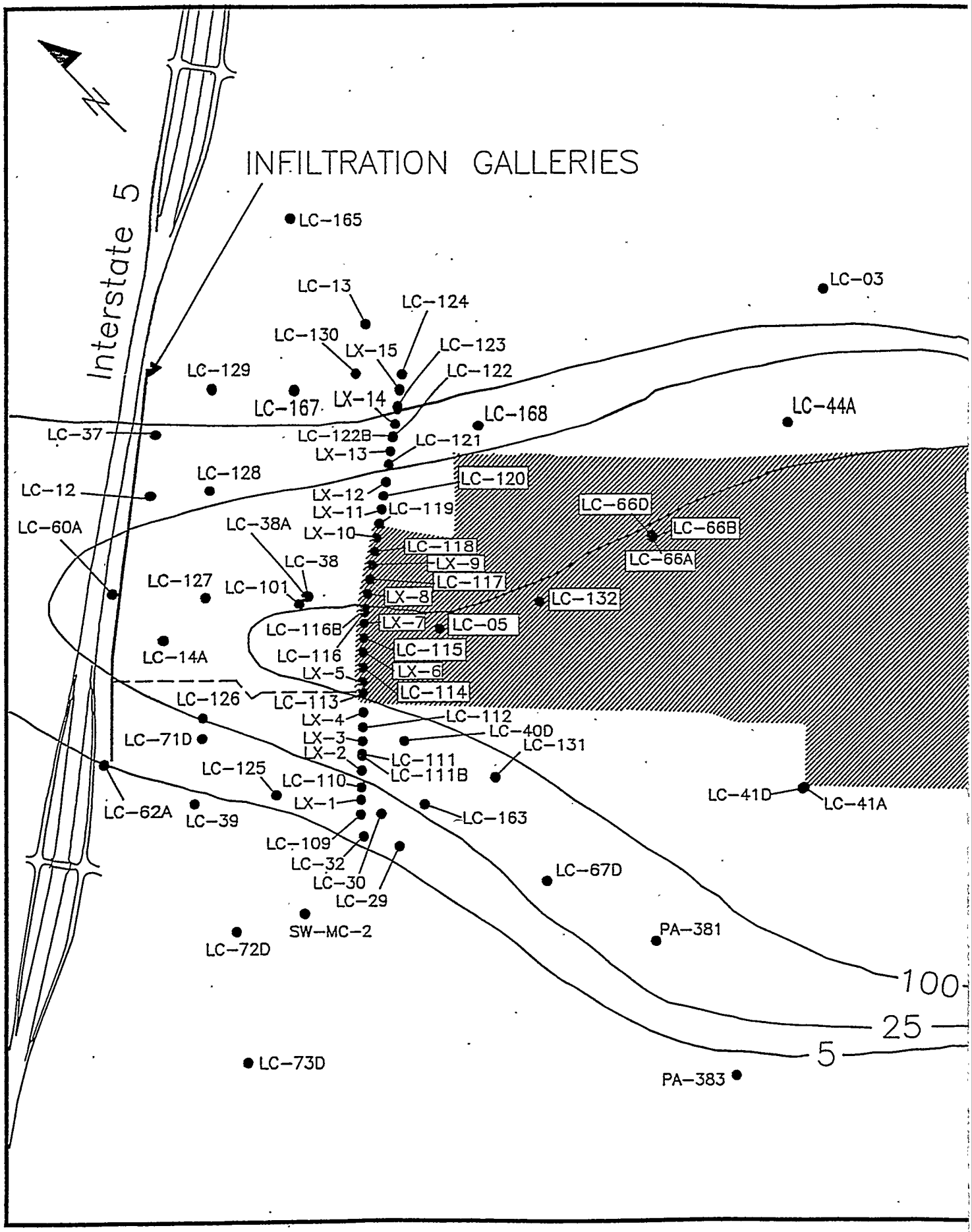
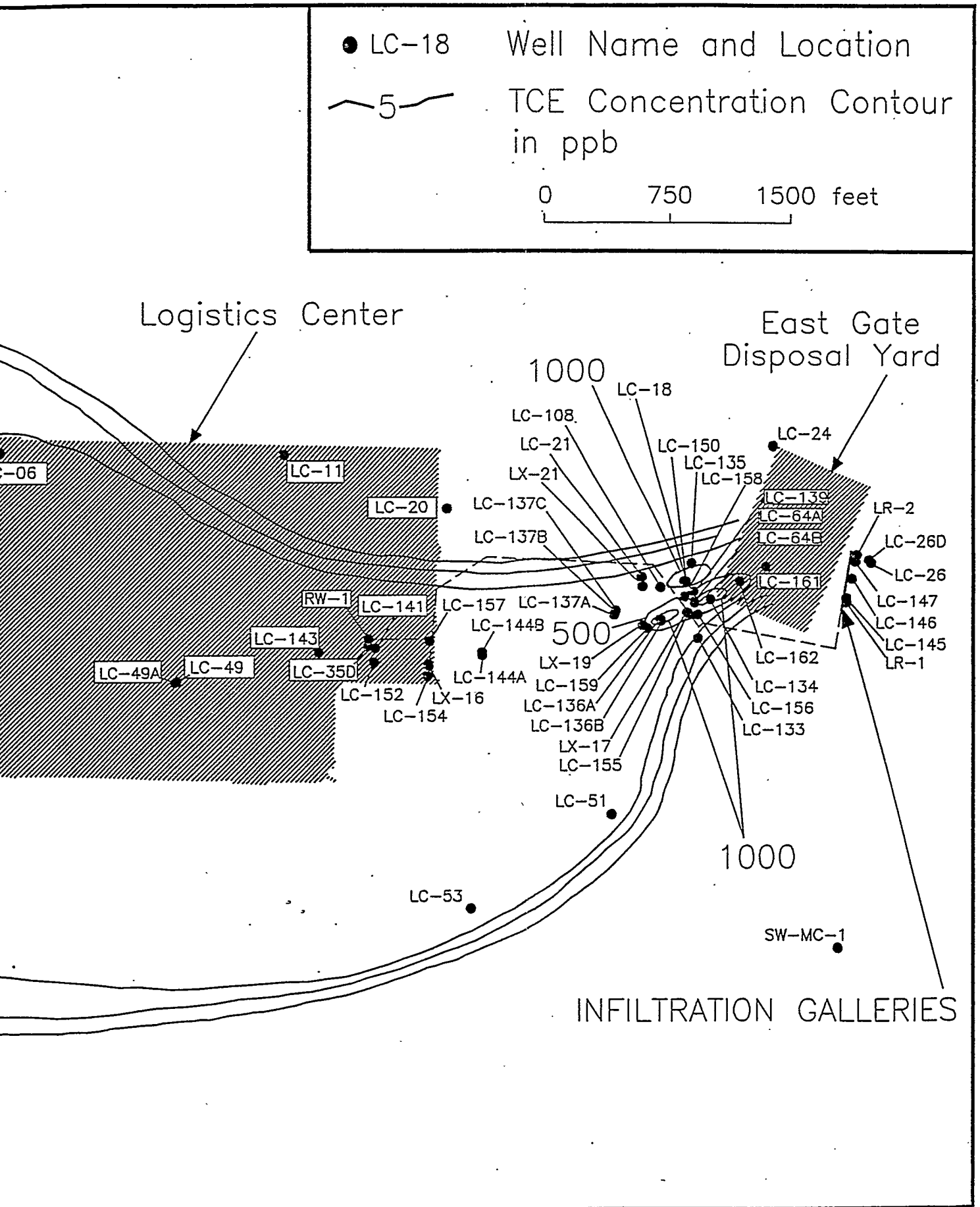


Figure 1.1. TCE Plume Beneath the Fort Lewis Logistics Center in 1996



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2.0 Background

TCE was used at the Logistics Center as a cleaning, degreasing, and hand washing solvent at several locations and under various conditions. Waste TCE commonly was mixed with grease, oil, and other petroleum products, as well as soil. This waste material, referred to as POL (petroleum, oil, and lubricants), was typically collected and stored in vats and drums for disposal. TCE use occurred primarily in Buildings 9580, 9570, and 9500, and over an extensive open area used for vehicle storage (Shannon & Wilson, Inc. 1986). Use of TCE at the Logistics Center ended in the mid-1970s and was replaced with trichloroethane (TCA).

The EGDY was used between 1946 and 1960 as an uncontrolled disposal site for waste generated by the Fort Lewis Mount Rainier Ordinance Depot (now included as part of the Logistics Center) (Shannon & Wilson, Inc. 1986). Aerial photographs indicate the EGDY was used between 1946 and approximately 1971 (Woodward-Clyde 1997a). Trenches were excavated in the yard and on adjacent land southwest of the yard, and may have intersected groundwater. Various wastes, including waste TCE and POL, were disposed of in these trenches. Reliable data regarding the quantity of TCE disposed are not available. Limited information is available from several interviews conducted by the U.S. Army Corps of Engineers (USACE) that contain conflicting recollections of past practices. It is estimated that six to eight drums of waste TCE and POL were disposed of per month from 1946 to 1960. At times, this material was used to assist in burning other waste materials at the site.

3.0 Hydrogeologic Framework

The general hydrogeologic profile beneath the Logistics Center is illustrated in Figure 3.1. Some of the more important features relevant to the site, including the EGDY, the East Gate and I-5 pump-and-treat systems, and selected wells, are also shown. The geology consists of a sequence of sand and gravel deposits that make up the Vashon Drift, or upper unconfined aquifer that overlies a sandy clay deposit known as the Kitsap Formation. The Kitsap Formation acts as an aquitard and overlies a thick sequence of alternating layers of sand and gravel and finer-grained unconsolidated sediments that make up the Salmon Springs Drift, or lower confined aquifer. The Salmon Springs Drift extends to a depth of at least 2000 ft (Shannon & Wilson, Inc. 1986).

In general, the sequence of deposits associated with the upper unconfined aquifer is highly variable and consists of permeable outwash deposits, tills, and nonglacial deposits. Recent deposits and the Steilacoom Gravels that overlie the Vashon Drift can be locally important and are part of the unconfined system. The aquifer is continuous across the site, but lateral and vertical changes in texture result in a highly heterogeneous unit. The total thickness of the aquifer varies with the elevation of the aquifer base that is formed by the clay of the Kitsap Formation. The thickness of the sand, gravel, and tills that make up the Vashon Drift vary from 90 to 130 ft across the site. Groundwater flow is generally to the northwest toward American Lake. With the exception of an erosional window near the center of the Logistics Center, the Kitsap Formation is believed to effectively isolate the upper unconfined aquifer from the lower confined aquifer. Flow directions in the lower confined aquifer are more westerly toward Puget Sound.

In the area of the EGDY, the water-table elevation is 270 ft above mean sea level (MSL) or 10 ft below ground surface (Woodward-Clyde 1997a). As shown in Figure 3.2, the tills within the Vashon Drift form a local aquitard surface at a relatively high elevation (250 ft MSL) directly beneath the western portion of the EGDY. This surface slopes broadly downward to 240 ft MSL in the southerly, south-easterly, and easterly directions. To the north-northwest, it slopes gradually to 245 ft MSL, then more steeply to 235 ft MSL to form a trough. Localized groundwater flow directions and the migration of any dense nonaqueous phase liquid (DNAPL) may be affected by this complex topography within the Vashon Drift.

Groundwater velocities in the upper unconfined aquifer are estimated to range between 0.03 and 26 ft/day (USACE 1998). At the median groundwater velocity of 1.5 ft/day, groundwater would require 14 years to travel from the EGDY to the I-5 groundwater extraction system (7800 ft). At the maximum measured velocity, it would require 300 days.

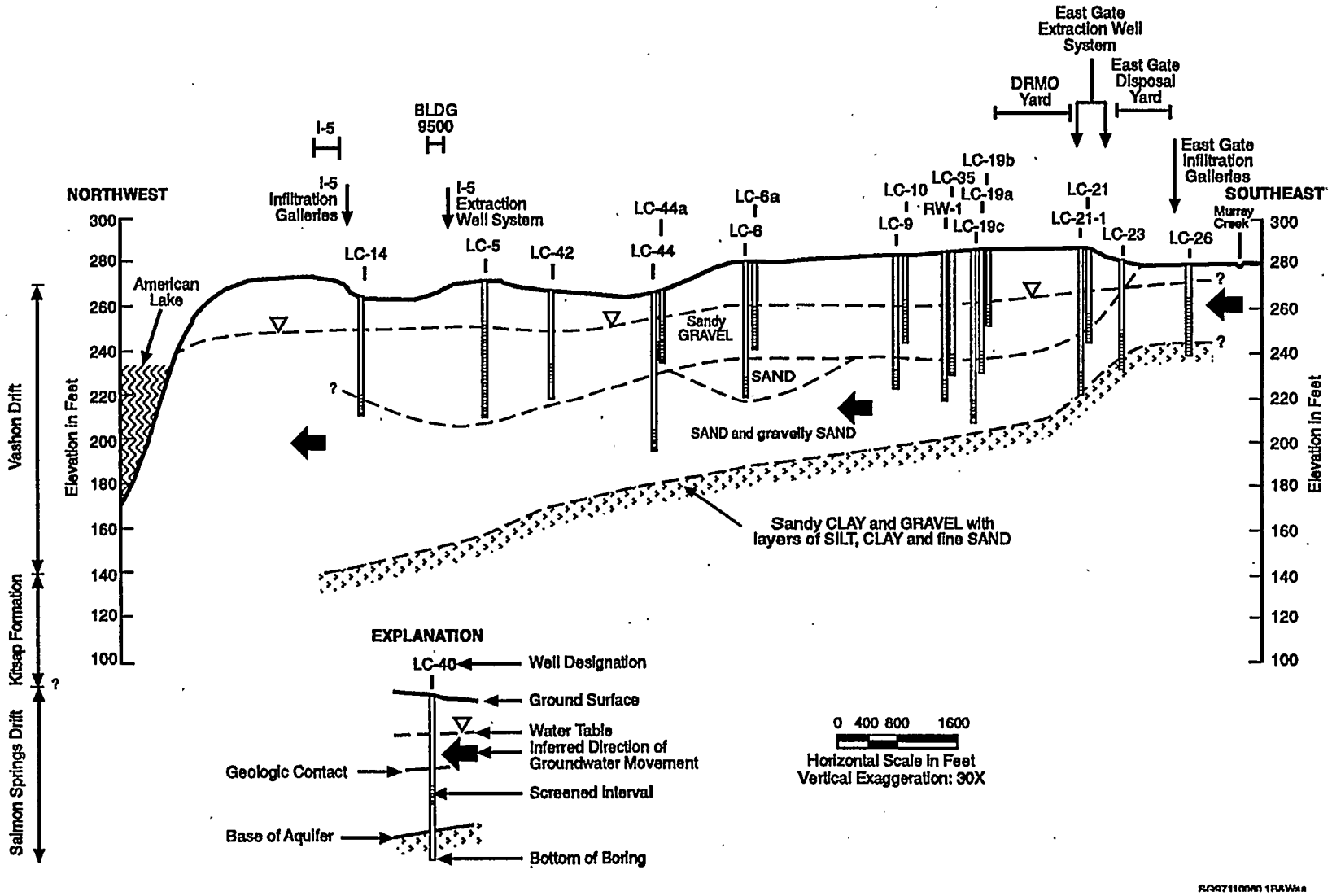

Figure 3.1. Hydrogeologic Framework at the Fort Lewis Logistics Center (modified from Shannon & Wilson, Inc. 1986)

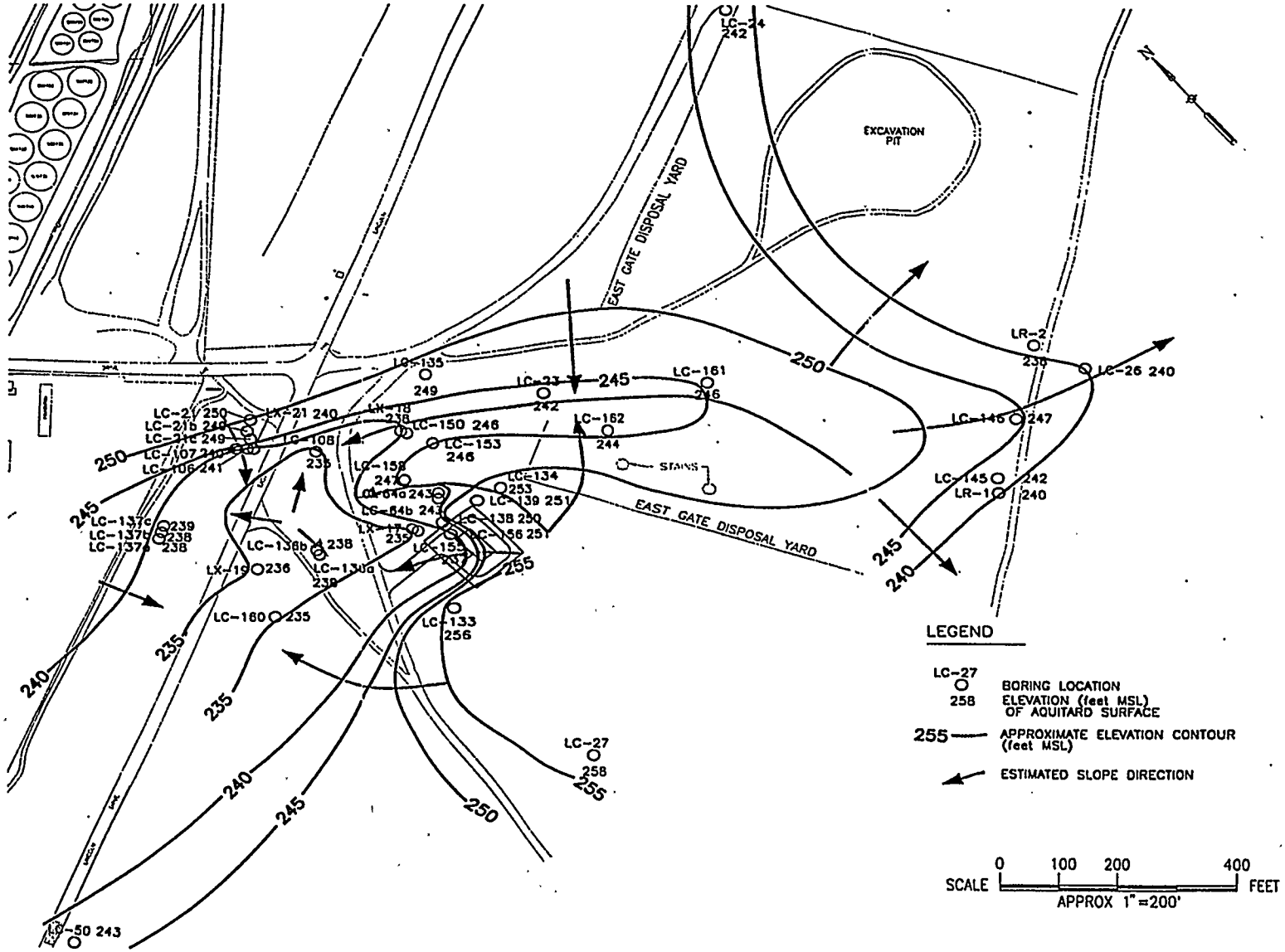

Figure 3.2. Local Aquitard Surface Formed by Tills Within the Vashon Drift (modified from Woodward-Clyde 1997a)

4.0 Source Term Evaluation

The mass of TCE that comprises the source term at the Logistics Center is highly uncertain (Shannon & Wilson, Inc. 1986). Recorded information regarding TCE use and disposal at the site is very limited and interviews conducted by the USACE resulted in conflicting recollections. Therefore, a three-step approach was used to assess the magnitude of the problem presented by this site and evaluate the effectiveness of the current treatment operations in remediating the problem. These steps included 1) determination of TCE mass at the source, 2) determination of TCE in the upper unconfined aquifer plume, and 3) determination of the mass removal rates by the two pump-and-treat systems.

4.1 TCE Mass at the Source

In order to make a determination of the quantity of TCE that might exist as the source term, it was assumed that one 55-gal drum of the 6 to 8 drums disposed of per month over the 14-year period (1946 through 1960) contained TCE. This assumption results in a total disposal of 51,000 kg of TCE. Although this estimate is highly uncertain (8 drums would total approximately 400,000 kg), it is useful for comparison purposes. The other source of uncertainty is related to how much TCE volatilized when it was disposed on the surface or burned.

4.2 TCE Mass in the Upper Unconfined Aquifer Plume

The quantity of TCE that exists in the upper unconfined aquifer plume was estimated using a plume map from Woodward-Clyde (1997b), which is based on data collected from 27 August 1996 to 3 October 1996 (see Figure 1.1). Using an average aquifer thickness of 60 ft and a porosity of 0.31, an estimated 2446 kg of TCE occurs in the dissolved phase of the plume. The amount of TCE adsorbed to the aquifer material was estimated by assuming an aquifer bulk density of 1.83 gm/cm^3 and an adsorption coefficient (K_d) of 0.17 L/kg, based on a retardation factor of 2 (Shannon & Wilson, Inc. 1986). A TCE retardation factor of 2 is typical for sand and gravel aquifers with low organic carbon content (Mackay et al. 1985). With these assumptions, the quantity of TCE adsorbed to the aquifer matrix in the plume is 2455 kg. Adding the dissolved and adsorbed fraction results in a total quantity of TCE in the aquifer of 4900 kg. The porosity and bulk density values were estimated from sieve analyses conducted at PNNL[a] on two Fort Lewis sediment samples collected at depths of 40 ft from borings located near wells LC-133 and LC-149.

The TCE mass in the aquifer was also calculated using parameters from previous transport modeling efforts (USACE 1998). In these calculations, a porosity value of 0.25 was used, bulk density was assumed to be 2.08 gm/cm^3, and the K_d value was 0.24 L/kg. These values resulted in 1972 kg of TCE occurring in the dissolved phase and 3939 kg of TCE adsorbed to the aquifer matrix, for a total of 5900 kg of TCE in the aquifer. This value is 21% larger than the value calculated in the previous paragraph.

(a) Jim Szecsody, PNNL, personal communication April 1998.

4.3 TCE Mass Removal Rate by the Pump-and-Treat Systems

The rate of TCE removal from the plume by the pump-and-treat systems can also be estimated using the mass balance data provided by Woodward-Clyde (1998). For the second year of operation, an estimated total of 324 to 667 kg of TCE per year was removed (161 to 248 kg from the I-5 system and 164 to 419 kg from the East Gate System).

For comparison, the mass balance components for TCE at the Fort Lewis Logistics Center are listed in Table 4.1. These results indicate the quantity of TCE that exists in the aquifer in the dissolved phase or adsorbed to the matrix is approximately 10% of that estimated to have been disposed. During the first 2 years of operation, the pump-and-treat systems have removed approximately 3% of the estimated source quantity. In the same time period, the pump-and-treat systems have removed between 13 and 27% of the TCE estimated to be in the aquifer at the start of the pump-and-treat operations.

Table 4.1. TCE Mass Balance at the Fort Lewis Logistics Center

Component	Mass (kg TCE)
Source term	51,000
Aquifer	4,900
Pump-and-treat systems	325 to 667 per year

Using the source term estimate in Table 4.1 and the current rate of removal by the pump-and-treat systems, at least 76 to 160 years will be required to remove all the TCE associated with the source term. Similar calculations indicate between 7 and 15 years would be required to remove the 4900 kg of TCE estimated to be in the aquifer at the beginning of pump-and-treat operations, assuming no degradation occurred in the efficiency of the pump-and-treat operations. However, the extraction efficiency of the pump-and-treat systems will likely decrease significantly through time as the high concentration portions of the plume are extracted. This system degradation will require a much longer time to meet the cleanup goals than estimated. If the source is underestimated, an even longer cleanup time will be required. These simple estimates for plume cleanup, when adjusted for performance degradation, are not consistent with either the 30 years specified in the ROD or the 40- to 45-year estimates made with more sophisticated models and reported in the Two Year Performance Evaluation report (USACE 1998).

4.4 Conceptual Site Model of TCE Transport

After disposal of liquids in the trenches at the EGDY, the conceptual site model of TCE transport begins with vertical movement of DNAPL through the unsaturated and saturated zones. Subsequent to disposal to the trenches, DNAPL would drain from the unsaturated zone, leaving residual liquids trapped on soil grains and in pore spaces. Depending on the rate of vaporization to soil gas and dissolution by water, residual DNAPL may or may not still remain in the unsaturated zone. Recent soil and soil gas concentrations suggest the DNAPL may be depleted from this zone. Planned work is expected to provide better evidence regarding this issue (Woodward-Clyde 1997a). TCE may also be present dissolved in a light nonaqueous phase liquid (LNAPL) floating on the water table as a result of co-disposal with the

POL. Depending on the amount of accumulated LNAPL, this material (if it exists) could be present for decades. Dissolution of TCE within an LNAPL phase would reduce its solubility and volatility.

Below the water table, DNAPL would be relatively stable because vaporization will be prevented and the rate of dissolution will be limited by the solubility of TCE (1600 mg/L) and the movement of water past the DNAPL phase. The DNAPL may have accumulated in depressions on the local aquitard surface, potentially forming large masses of material.

Dissolved contamination appears to enter the upper unconfined aquifer at or near the EGDY and migrates downgradient as a plume, along the axis of the Logistics Center (see Figure 1.1). TCE concentrations near the EGDY generally range from 500 to >50,000 µg/L. Throughout the main body of the plume, TCE concentrations range from 100 to 200 µg/L. The TCE concentration at the definable leading edge of the plume, adjacent to I-5, is 50 µg/L. The leading edge of the plume downgradient (under Tillicum) is not well-defined. DCE concentrations near the EGDY generally range from 100 to >500 µg/L, and from 10 to 50 µg/L throughout the main body of the plume. Vinyl chloride concentrations in the upper unconfined aquifer have been below detection in all but two wells, LC-134 and LC-162.

Laboratory data and field experience have suggested that dissolved TCE concentrations in excess of about 10,000 µg/L are indicative of the existence of DNAPL droplets or pools in the subsurface (Feenstra and Cherry 1996). Because dissolved aqueous TCE concentrations at well LC-136A exceed 10,000 µg/L (up to 80,000 µg/L), it is probable that some DNAPL is present in the upper unconfined aquifer near the EGDY. The presence of subsurface DNAPL generally complicates the cleanup of a contaminated site.

5.0 Evaluation of Existing Pump-and-Treat Systems

The pump-and-treat systems at the Logistics Center have been in operation since 31 August 1995. Groundwater monitoring results collected to date suggest the system is containing the TCE plume in the upper unconfined aquifer and preventing further expansion (Woodward-Clyde 1997a, 1997b; USACE 1998; EPA 1997[a]). However, based on the

1. mass of TCE in the source term (51,000 kg)
2. amount of TCE estimated in the aquifer (4900 kg)
3. quantity of TCE being removed by the pump-and-treat systems (325 to 667 kg/year)

the pump-and-treat systems alone are not likely to effectively clean up the TCE at this site within the projected time frame. The remedial action objective of restoring the aquifer to a drinking water source within 30 years as specified in the ROD will not be met, unless additional remedial activities are undertaken in the EGDY area to deal with the source term.

Several model simulations have been conducted to estimate the time required for the pump-and-treat systems to meet cleanup goals (USACE 1998). The results of these simulations indicate a cleanup time of 40 to 45 years. The model also assumes that a constant concentration at existing contamination levels is present in the EGDY area, but does not specifically deal with the potential DNAPL source. This assumption was made because the source term was unknown. As a result, the simulated cleanup times only address treatment of the existing plume and not the total cleanup problem that must include the actual source term quantity, its location, and a method for removal or treatment.

(a) Five Year Review Report, Fort Lewis Logistics Center, U.S. EPA, September 1997 (unpublished).

6.0 Enhancements to Existing Treatment Operations

Four treatment areas have been identified (Figure 6.1) to more easily evaluate the potential for innovative technology enhancements to the existing treatment operations at the Logistics Center. Area 1 is the vadose zone source at or near the EGDY. Area 2 is the saturated zone source beneath the EGDY. Area 3 is a containment area downgradient of Areas 1 and 2. Area 4 is the remainder of the upper unconfined aquifer plume.

6.1 Vadose Zone Source – Area 1

Area 1 is comprised of the vadose zone at or near the EGDY. The EGDY was used from 1946 to 1960 as an uncontrolled waste disposal site. An estimated mass of 51,000 kg of TCE was disposed of in trenches excavated in the yard and on adjacent land southwest of the yard. Residual DNAPL may be trapped on soil grains and in pore spaces depending on the rate of vaporization to soil gas and dissolution by water. Woodward-Clyde (1997a) indicates that, due to its high volatility and the amount of time that has passed since TCE was last disposed, pure product is probably no longer present in the unsaturated zone. TCE was last disposed in the EGDY approximately 25 years ago. Subsequently, only one soil sample, collected from soil borings taken at 23 different locations within the EGDY, indicated the presence of free product. Expanded site investigation activities at the EGDY will be conducted beginning in September 1998 that will focus specifically on the former trench areas (Woodward-Clyde 1997a). This new characterization data should provide better evidence concerning the significance of TCE in the vadose zone.

6.2 Saturated Zone Source – Area 2

Area 2 is comprised of the saturated zone within the upper unconfined aquifer immediately beneath Area 1. The relatively short distance to groundwater (10 ft, less the trench depth) indicates it is probable that nonaqueous phase liquids (NAPL) have migrated to the aquifer at the EGDY. The occurrence of dissolved TCE at levels greater than 80,000 µg/L near the EGDY (well LC-136A) strongly suggests the presence of DNAPL in the upper unconfined aquifer. Localized groundwater flow directions and the migration of DNAPL may be affected by the complex topography of the local aquitard surface. Further characterization to be conducted by Woodward-Clyde (1997a) should provide a better idea of the quantity and location of the DNAPL. The presence and quantity of DNAPL originating from the EGDY is the single most important factor governing the longevity of the cleanup at the Logistics Center.

6.3 Containment Zone – Area 3

Area 3 is a containment area within the upper unconfined aquifer downgradient of Areas 1 and 2. This area is a potential location for a containment technology (permeable barrier) that could be used to reduce migration of TCE from Areas 1 and 2 to the rest of the aquifer (Area 4). Planned characterization work to be conducted by Woodward-Clyde (1997a) is expected to allow for a more detailed determination of the best location for such a barrier.

6.4 Remainder of the Plume – Area 4

The remainder of the TCE plume downgradient of Area 3 and within the upper unconfined aquifer comprises Area 4. Although it is likely that uncontrolled releases of TCE to the ground occurred within Area 4 in the past, the quantity of material released was probably small relative to that disposed at the EGDY. In addition, the distance to the aquifer below land surface is greater within Area 4 than at the EGDY. Therefore, any TCE released to the ground is likely to have partially volatilized. Elimination or isolation of the source term from Areas 1 and 2 would significantly reduce the time required for remediation of Area 4.

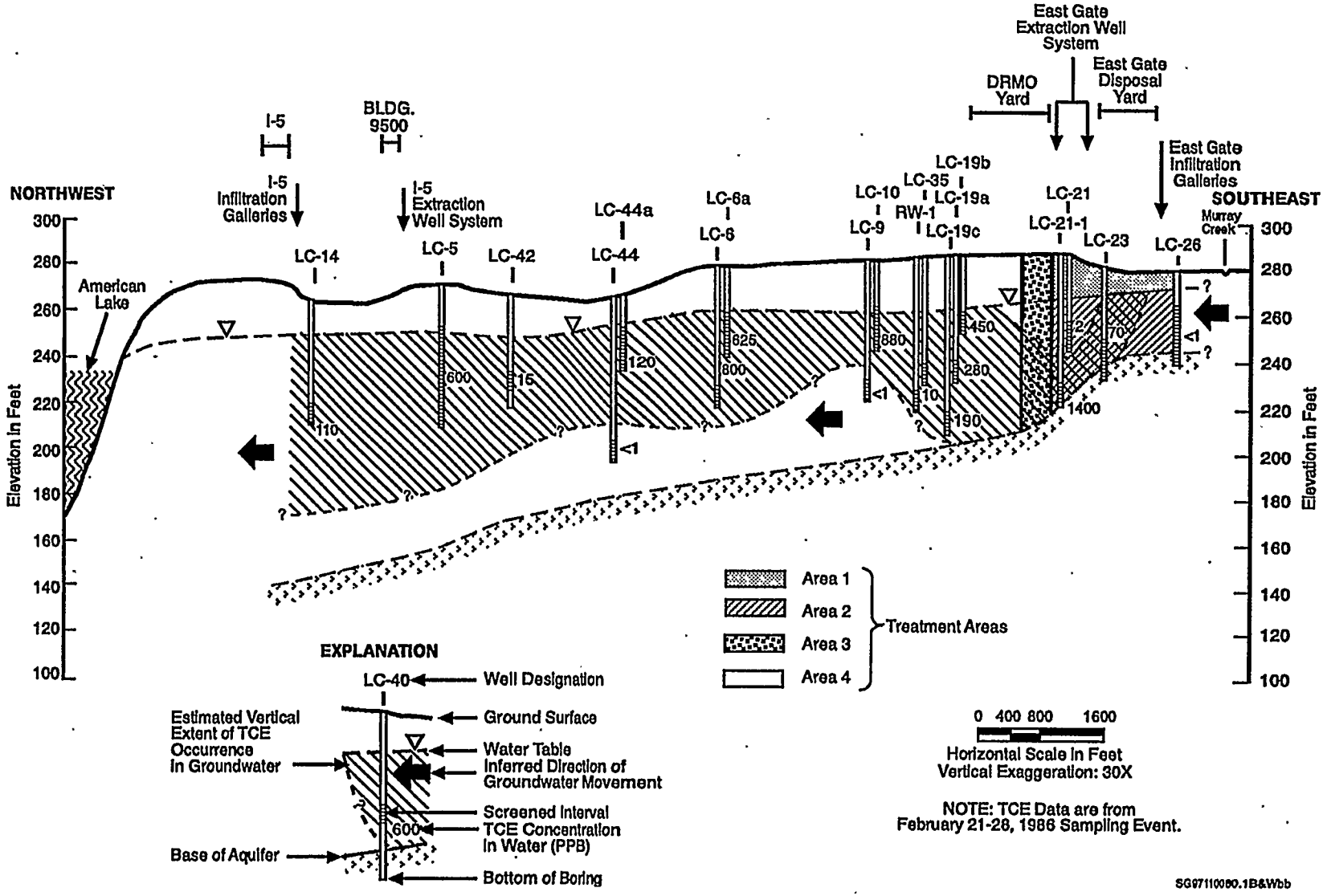

Figure 6.1. Enhancements to Existing Treatment Operations at the Fort Lewis Logistics Center (modified from Shannon & Wilson, Inc. 1986)

7.0 Innovative Technology Options

Table 7.1 provides a list of potentially useful remedial technologies, including new and innovative (nonstandard) technologies that can treat or remove TCE in the environment. This table may be used to screen applicable technologies for more detailed study, and to help in assembling potential treatment trains or systems that incorporate the individual technologies. The technologies have been grouped according to the four treatment areas (see Figure 6.1). The overall strategy for a site remedy will determine how each treatment area is managed and, therefore, which technologies are selected.

Table 7.1. Potential TCE Remedial Technologies

Fort Lewis Treatment Area				Targeted Medium	General Response Action	General Remedial Process	Remedial Process Option	Potential Innovative Technology	Technology Description
1	2	3	4						
X				Soil	Containment	Prevent infiltration	Capping		A surface barrier is placed over the contaminated source area to reduce water infiltration through the waste. This action slows the spread of contamination though the vadose zone and delays/reduces the contamination of the aquifer.
X					In situ treatment	Biodegradation	Bioventing		Bioventing is similar to soil vapor extraction, except that in situ biodegradation is stimulated intentionally. This process not only physically removes volatile organic compounds (VOC) in the soil gas, but it also provides oxygen, moisture, nutrients, and possibly microorganisms to stimulate in situ biodegradation of residual organic contaminants.
X						Physical	Solidification/ stabilization	Jet grouting	Jet grouting reduces the mobility of hazardous constituents by injecting a solidification agent that mixes with the contaminated soil at high pressures (up to 6000 psi) as the injection pipe is rotated and drawn up. This process forms a cylindrical column of solidified soil. Placement of subsequent injections allows formation of subsurface walls or monoliths.
X							Thermal enhancements		Uses steam, heated water, or radio frequency, or electric resistance heating to alter temperature-dependent properties of contaminants in situ to facilitate their mobilization, solubilization, and removal.
X						Chemical	Reduction	IGRS (H_2S)	In situ gaseous reduction system (IGRS) utilizes the reductive properties of H_2S to reduce a contaminant directly or uses an intermediary such as Fe^{+2} to reduce the contaminant. ISGR has been successfully field tested for in situ reduction of Cr^{+6} to Cr^{+3}. However, it is still in the development stage for solvents (for example, TCE) and explosives.
X					Removal	Physical	Soil vapor extraction (SVE)	6-Phase Soil Heating™	Six-Phase Soil Heating (SPSH) is an emerging technology for thermally enhancing the removal of volatile and semi-volatile organic compounds from soils in conjunction with conventional soil vapor extraction (SVE). This resistive heating technique facilitates uniform heating throughout the volume bounded by six electrodes. An extraction pipe in the center of the hexagon is used to extract contaminated steam and gases. By raising the temperature of the soil and contaminant, the contaminant's vapor pressure is increased, thus increasing its removal rate.
	X						Electrokinetics	LASAGNA™	This technology extracts contaminants from low-permeability clay soils by electroosmosis. An electric field between two subsurface electrodes causes the accelerated movement of water and contaminants toward higher-permeability treatment zones. Application of this technology may require coupling to a soil vapor extraction system due to heating of subsurface.

Table 7.1. (contd)

Fort Lewis Treatment Area				Targeted Medium	General Response Action	General Remedial Process	Remedial Process Option	Potential Innovative Technology	Technology Description
1	2	3	4						
	X			Groundwater	Containment	Physical	Solidification/ stabilization	Jet grouting	Jet grouting reduces the mobility of hazardous constituents by injecting a solidification agent that mixes with the contaminated soil at high pressures (up to 6000 psi) as the injection pipe is rotated and drawn up. This process forms a cylindrical column of solidified soil. Placement of subsequent injections allows formation of impermeable subsurface walls or monoliths to contain the contamination.
	X				In situ treatment	Chemical	Reduction	Reactive wells	This technology uses a single groundwater well to extract, treat, and recirculate the groundwater. A variety of treatments is possible, including the use of reducing agents. Once treated, the partially treated groundwater is forced out of the well into the vadose zone where it reinfiltrates to the water table. Untreated groundwater enters the well at its base, replacing the water lifted through pumping. Eventually, the partially treated water is cycled back through the well until contaminant concentration goals are met.
	X						Reduction	In-well vapor stripping	This technology creates a groundwater circulation pattern and simultaneous aeration within the stripping well to volatilize VOCs from the circulating groundwater. Air-lift pumping is used to lift the groundwater and strip it of contaminants. Partially treated groundwater is forced out of the well into the vadose zone where it reinfiltrates to the water table. Untreated groundwater enters the well at its base, replacing the water lifted through pumping. Eventually, the partially treated water is cycled back through the well until contaminant concentration goals are met.
	X						Oxidation	Geo-Cleanse™	The Geo-Cleanse process is based on Fenton's Reagent Chemistry. This process uses hydrogen peroxide and traces of ferrous iron mixed with stabilizers and surfactants to create a hydroxyl free radical that oxidizes the carbon bonds of chlorinated hydrocarbons, such as TCE, reducing the contaminants to carbon dioxide, oxygen, and water.
	X				Removal	Physical	Air sparging		Air sparging reduces concentrations of volatile constituents that are adsorbed to soils and dissolved in groundwater. Sparging injects contaminant-free air into the saturated zone, enabling a phase transfer of the target contaminants from a dissolved state to a vapor phase. The air is then vented through the unsaturated zone. Air sparging is often used together with SVE.
	X						In situ flushing		This technology injects or infiltrates a solution into a zone of contaminated groundwater, followed by downgradient extraction of groundwater and eluate. Solutions may consist of surfactants, cosolvents, acids, bases, solvents, or water.

Table 7.1: (contd)

Fort Lewis Treatment Area				Targeted Medium	General Response Action	General Remedial Process	Remedial Process Option	Potential Innovative Technology	Technology Description
1	2	3	4						
	X						Electrokinetics	LASAGNA™	This technology extracts contaminants from low-permeability clay soils by electroosmosis. An electric field between two subsurface electrodes causes the accelerated movement of water and contaminants toward higher-permeability treatment zones. This technology has been field-tested, but may need to be coupled to soil vapor extraction system due to subsurface heating.
	X					Chemical	Solvent flushing		Solvent flushing involves injecting a solvent mixture (such as water plus a miscible organic solvent, such as alcohol) into either the vadose zone, saturated zone, or both to extract organic contaminants. It can be applied to either the source of contamination or the contaminant plume emanating from it. The cosolvent mixture is normally injected upgradient of the contaminated area, and the solvent with the dissolved contaminants is extracted downgradient and treated aboveground.
		X			Containment	Hydrologic control	Sheet piles (impermeable)		Sheeting piling is used to construct subsurface barriers to contain or divert contaminated groundwater, divert uncontaminated groundwater flow, or provide a barrier for the groundwater treatment system.
		X				Physical	Slurry/grout barrier (impermeable)		Slurry walls are subsurface barriers consisting of a vertically excavated trench filled with a slurry to contain contaminated groundwater, divert contaminated groundwater from the drinking water intake, divert uncontaminated groundwater flow, or provide a barrier for the groundwater treatment system.
		X			In situ treatment	Chemical	Reduction	Metallic iron barrier (funnel and gate; soil mixing; hydrofracting)	This technology uses a permeable wall consisting of iron granules or other iron bearing minerals to treat chlorinated contaminants such as TCE, DCE, and VC. These walls can be constructed by a number of techniques and configurations. As the iron is oxidized, a chlorine atom is removed from the compound by one or more reductive dechlorination mechanisms, using electrons supplied by the oxidation of iron. The iron granules are dissolved by the process, but the metal disappears so slowly that these remediation barriers can remain effective for many years.
		X						In situ redox manipulation (sodium dithionite)	This technology creates a reactive barrier by injecting sodium dithionite into the aquifer. The sodium dithionite ($Na_2S_2O_4$), dissociates into sulfoxyl radicals and interacts with the iron in the subsurface. This changes the oxidation state of the native iron and creates a reactive zone analogous to a zero-valent (metallic) iron wall. As the iron is re-oxidized by the aquifer, the contaminants are either reduced, or dechlorinated, using electrons supplied by the oxidation of iron.

Table 7.1. (contd)

Fort Lewis Treatment Area				Targeted Medium	General Response Action	General Remedial Process	Remedial Process Option	Potential Innovative Technology	Technology Description
1	2	3	4						
		X					Oxidation	Permanganate	This process uses potassium permanganate to oxidize dissolved chlorinated solvents (e.g., PCE, TCE, and DCE) and/or residual DNAPLs in remedial schemes involving either source zone flooding or reactive barriers.
		X			Removal	Physical	Extraction wells		Groundwater pumping is a component of many pump-and-treat processes. The design of the extraction well network, pumping system, and treatment are dependent on the physical site characteristics and contaminant types. Treatment may include the design of a train of processes, such as gravity segregation, air strippers, and carbon systems tailored to remove specific contaminants.
		X			Enhancement technologies	Physical	Hydraulic and pneumatic fracturing		These two technologies induce fractures in the subsurface to enhance the remediation of contaminants above and below the water table. They are particularly useful and cost-effective at sites with low-permeability soil.
		X					Directional wells		Trenched or directly drilled wells installed at any non-vertical inclination. Especially useful when surface obstructions are present.
		X	X		Containment	Hydrologic control	Extraction wells		Groundwater pumping is a component of many pump-and-treat processes and is used as a hydraulic barrier to prevent off-site migration of contaminant plumes.
			X	Soil	Removal	Physical	Soil vapor extraction (SVE)	Passive pumping (using barometric changes)	This technology enhances air flow in the unsaturated zone that results from natural atmospheric pressure variations (e.g., barometric pumping); thus, causing volatile organic contaminants (VOC) to be extracted from the subsurface.
			X	Groundwater	No action	No action	Natural attenuation		Natural attenuation makes use of natural processes to contain the spread of contamination. This requires careful study of site conditions and monitoring of contaminant levels.
			X		Institutional control	Control groundwater usage	Point-of-use treatment		This technology relies on ex situ water treatment technologies to treat the water at municipal water supply facilities prior to its use for public consumption.
			X				Deed restrictions		Land use restrictions are required to limit the use of the land or groundwater to avoid adverse human health effects.
			X		In situ treatment	Biodegradation	Bioremediation (bioamendments)		Aerobic co-metabolism of TCE with phenol, toluene, phenal, methane, ammonia, isopreme, or propane.
			X				Phytoremediation (poplar trees)		General use of plants to remediate environmental media in situ. Includes rhizofiltration, phytoextraction, phytotransformation, phytostimulation (plant-assisted bioremediation), and phytostabilization. May require periodic harvesting of plants.

8.0 Conclusions

Using a TCE mass balance approach shows that it is very unlikely that existing pump-and-treat systems alone will accomplish the remedial action objective of cleaning up the aquifer to drinking water standards within 30 years as specified in the ROD. This conclusion is based on the estimated mass of TCE at the source term (51,000 kg), the mass of TCE calculated to be in the aquifer (4900 kg), and the removal rate of the two pump-and-treat systems (currently 324 to 667 kg of TCE per year). Assuming this removal rate remains constant and volatilization is insignificant, it would require between 76 and 160 years to clean up the aquifer. In practice, however, the actual cleanup time will likely increase due to the continuous decrease in extraction efficiency of the pump-and-treat systems.

Four areas within the TCE plume have been identified for enhancing the existing treatment operations. Area 1 is the vadose zone source. Area 2 is the saturated zone source within the upper unconfined aquifer beneath Area 1. Area 3 is a containment area downgradient of Areas 1 and 2. The remainder of the plume within the upper unconfined aquifer that is downgradient of Area 3 comprises Area 4. Several remedial technologies, including new and innovative (nonstandard) technologies have been identified in this report that may help clean up the site to regulatory acceptable levels, shorten the timeframe for cleanup, and significantly reduce IRP costs. Clearly, the greatest reduction in time for remediation would be achieved through removal or treatment of the source, based on the estimated TCE mass disposed in the EGDY. Planned characterization activities will likely preclude any source-term remediation at this time.

9.0 References

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